Advanced Doppler Radar

1a. Describe the Doppler radar theory and the radar detection process.

Doppler Theory

- Electromagnetic Waves
  - Electromagnetic energy is emitted in the form of waves
  - Electromagnetic energy has three important characteristics, which affect radar performance
    - Wavelength
      - The wavelength of the energy is measured between successive troughs or crests in the sine waves and are typically measured in centimeters (cm)
      - Other factors being equal, the echo return from clouds or precipitation increases with shorter wavelengths

Doppler Theory

  - Within the wavelengths used for weather radar, the smaller droplets are more visible to the radar at the shorter wavelengths and are more transparent at the longer wavelengths

- Amplitude
  - A waves height, is called amplitude and represents the amount of energy, or power contained within the wave
  - The greater the amplitude the more power returned
- Frequency
  - Radar frequency refers to the number of completed waves (cycles) per second
  - Frequency and wavelength are closely related changes in one have a direct impact on the other This relationship will be discussed in more detail later in the chapter

Doppler Theory

- Beam characteristics
  - **Beam Width -To properly interpret data from weather radar, it is necessary to define the radar beam in terms of half-power points**
    - Maximum power density (power per unit area) exists along the centerline of the beam
    - To each side of this beam centerline the power drops off gradually at first, then more sharply as the distance from the centerline increases
    - A half-power point exists at a distance where power density is one-half that of the centerline, for a given range

Doppler Theory

- As a result of this power concentration along the centerline, nearly 80% of the total radar energy actually is contained inside these half-power points
- Since the beam is cone-shaped, half-power points combine to make a circle
- The diameter of this circle is the beam width or diameter This bounded area constitutes the "radar beam"
- Under most circumstances, this "radar beam" is the area where enough backscattered energy is available to detect a target
- Backscattered radiation from outside this area is usually too weak to be detected by the radar

Doppler Theory

- **Beam Broadening – Beam broadening is a term used to describe the cone-like appearance as it travels away from the antenna.**
  - This expansion of beam broadening increases pulse volume, which is the volume of the atmosphere occupied by the radar pulse, resulting in decreased signal strength.
  - Distant targets appear weak; in fact they may not be seen at all.
  - Beam broadening also causes partial beam filling which describes the effect that occurs when a target fills only a small portion of the radar beam.

Doppler Theory

- Anytime a target occupies only a small portion of the beam, the true characteristics of that target may be hidden or altered during display.

Doppler Theory

- **Sample volume – A Sample volume is defined as the volume of the atmosphere, which is instantaneously sampled by the radar.**
  - If measured, the actual dimensions of a sample volume are 13 nm in length, by 1° width
  - Since the sample volume is relatively large, individual targets are much smaller than the echoing volume
  - This means that all targets within that volume contribute to backscattered radiation received by the radar
  - In other words, the individual character of a target is averaged among the characteristics of other targets

Doppler Theory

- If all targets are similar to each other, this is not a problem, but if a few targets are very different, their special characteristics can be lost among the total average

Doppler Theory

- **Propagation of the Radar Beam**
  - The propagation of energy along a radar beam does not coincide with a straight line path from the transmitter
  - The actual path of the radar beam is curved
  - This curved path is the effect of refraction, or bending, as the beam passes through the atmosphere
    - Standard Refraction
      - » In the atmosphere, the refractive index does not remain constant with height
      - » Under normal atmospheric conditions, the temperature and water vapor content gradually decrease as height increases

Doppler Theory

- These normal atmospheric properties refract the radar beam at a curvature less than the earth’s surface curvature
- This causes the beam to increase with height as it propagates away from the antenna

Doppler Theory

- Superrefraction
  - » When warm, dry air overlies relatively cool, moist air, as in an inversion, superrefraction may occur
  - » In this case, the radar beam is refracted below its normal path
  - » The greater the increase of temperature and decrease of moisture, or both, with height, the greater the degree of superrefraction
  - » In an extreme case, low level targets a few hundred miles distant, and not normally detected, may be displayed by the radar

Doppler Theory

- Probably one of the greatest limitations caused by superrefraction is the *overestimating* of cloud/precipitation heights
- As the beam bends below its normal path, it strikes a target and returns energy to the radar
- This return energy is interpreted by radar based on the standard refraction of a radar beam
- Thus, the actual height of the cloud/precipitation is lower than the displayed height values

Doppler Theory

- Subrefraction
  - » Straightening of the beam upward, or subrefraction, may occur during atmospheric conditions where the water vapors content increases with height and the temperature decreases with height
  - » Subrefraction reduces the maximum range of detection of low-level targets because the beam quickly overshoots these low targets
  - » Such a condition may occur in certain types of fog, but it does not occur in precipitation
  - » This abnormal condition is relatively unimportant for storm detection

Doppler Theory

- As with superrefraction, subrefraction has a limitation on displayed cloud/precipitation heights
- As the radar beam bends above its normal path, it strikes a target and returns energy to the radar
- This return energy is interpreted by radar based on the standard refraction of the radar beam
- Thus, the actual height of the cloud/precipitation is higher than the displayed height values

Doppler Theory

- Pulse Repetition Frequency
  - **The pulse repetition frequency (PRF) is defined as the rate at which pulses are transmitted per second or PPS (pulses per second)**
    - Listening Time – The period of waiting for a returned signal, the listening time, determines the maximum range of the radar.
    - The listening time permits the energy, which has been backscattered from the target to be received before the next pulse is transmitted
    - The range of a radar is equal to one half the maximum distance (round trip) the signal can travel during the listening time – the time between pulses

Doppler Theory

- The radar is dependent upon a combination of pulse length which is the distance from the front (leading) edge to the back (trailing) edge of the pulse as it travels in space, and listening time
- They determine some of the capabilities of the radar to detect the weather

Doppler Theory

- **Choose the correct PRF**
  - Although the PRF must be kept low to allow for the maximum range desired, it must also be kept high enough to allow a sufficient number of pulses to be returned from a distant target
  - Remember, the power of the returned signal is very low and many returns are needed to present a target accurately and with enough detail to be interpreted
  - If only one pulse were transmitted to and received from a given target, the reliability of the radar presentation would be poor
  - Therefore, radar is designed so that many pulses are returned from a single target

Doppler Theory

- Antenna Motion
  - **An important consideration in determining the number of pulses reflected from a target is the antenna's rate of rotation**
  - **If the antenna rotates too fast, not only is the number of pulses per target too low, but there may be regions not probed for targets**
  - **The rate of rotation by the radar is expressed in terms of pulses per degree**

Doppler Theory

- **This number must be kept high enough to allow adequate sampling of targets, while at the same time be low enough so it does not take an inordinate amount of time to finish a 360˚ scan**

Doppler Theory

- Maximum Unambiguous Range
  - **The maximum distance electromagnetic energy can travel round trip between pulses defines the maximum range of a radar system**
  - **This range limit, called the unambiguoys range, is limited by how often pulses are broadcast, put simply the PRF determines the range of the radar**
  - **PRT, pulse repetition time, is the amount of time between pulses (listening time)**

Doppler Theory

- **The greater the PRF (pulses per second), the shorter the PRT, and the shorter the unambiguous range of the radar**
- **Short intervals between pulses restrict the range of the radar**
- **Short pulses and short pulse intervals provide the utmost accuracy and detail of targets**
- **Long pulse intervals increase the range of the radar and long pulses increase its sensitivity**

Doppler Theory

- Range Folding (Second-Trip Echoes)
  - **A pulsed radar system measures distance by keeping track of pulse travel time**
  - **However, the radar cannot distinguish one pulse from another, that is, all returned pulses look the same to the receiver, it cannot distinguish energy of a previous pulse from a more recent pulse**
  - **The radar depicts a target as though the energy were returned from the most recent pulse**

Doppler Theory

- **When energy is received from an old pulse after transmission of the next pulse, the radar assumes the returned energy is from the lastest pulse, essentially it gave up looking for the old pulse and sent a new one**
- **Therefore, the displayed echo is at a distance equal to ½ the distance traveled by the latest pulse**
- **The target azimuth is correct but the range is incorrect**
- **This phenomenon is known as range folding, or second trip echoes as we have called it in the past**

Doppler Theory

- **Range folded echoes can be identified if you are aware of their characteristics**
- **They are typically elongated along a radial, indistinct in appearance, but most intense on the side nearest the radar**
- **They disappear with a change in antenna elevation angle, and change display range if the PRF is changed**

Doppler Theory

- Sampling Limitations
  - **A sampling limitation is defined as a certain radar characteristic or undesirable radar echo whose effects cannot be mitigated by the operator**

Doppler Theory

- **In other words, there is no way to "fix" radar results caused by sampling limitations, but it is important to know that they exist and how they effect the radar detection process**
  - Signal Attenuation
    - As electromagnetic waves emitted from
    - This is the result of interaction with radar travel through the atmosphere, some of the energy is lost to atmospheric phenomenon such as hydrometers, (clouds and precipitation), gasses, and lithometers (smoke, dust, haze, etc)
    - This loss of energy due to interaction with atmospheric phenomenon is called attenuation

Doppler Theory

- Partial Beam Filling
  - Partial beam filling is defined as the effect that occurs when a target fills only a small portion of the radar beam
  - Keep in mind that, as the radar beam propagates away from the radar, it continually becomes wider – quite wide at distant ranges
  - As a result, targets occupy a much smaller portion of the beam at these distant ranges
  - This results in the return of relatively small amounts of energy – our displayed echo is weaker than the true echo

Doppler Theory

- Anytime a target occupies only a small portion of the beam, the true characteristics of that target may be hidden or altered during display
- In shallow precipitaion regimes, the result could be an absence of precipitation echoes being displayed even though substantial rainfall is occurring
- While detecting showers or thunderstorms, beam filling must be considered both horizontally and vertically
- Some showers are less than 1 mile in width and may not completely fill a narrow 1° beam at ranges beyond 60 miles
- In addition, the most intense core of a storm may cover only a small percentage of the entire storm
- This also results in a comparatively weaker return

Doppler Theory

- Below beam effect
  - Below beam effects are the result of evaporation or growth of precipitation below the radar beam
  - At greater ranges with larger sampling volumes and increasing beam heights, the accuracy of these measurements diminishes—radar estimates of rainfall rates become less reliable at greater distances
  - Virga, the total evaporation of precipitating water, is an extreme example of below beam effects
  - Precipiation displayed at long range by the radar may not be reaching the ground
  - Only from actual surface observations could you tell that precipitation was not reaching the ground

Doppler Theory

- Large, low based thunderstorms can cause the opposite effect
- The area of maximum reflectivity is below the radar beam
- Therefore, little or no precipitation is being indicated
- In fact, surface observations would indicate heavy rainfall rates
- With these examples in mind, you should see the value of consulting other data sources to confirm radar displays. Surface observations, PIREP's, satellite imagery, and nearby radar reports are all helpful in overcoming this limitation

Doppler Theory

- Beam blockage
  - Beam blockage is another potentially serious source of error affecting the radar beam
  - Blockage is not a shortcoming of the radar
  - Rather, it is caused by obstructions of the beam by targets close to the antenna
  - The result of blockage can often be seen as part of the ground clutter pattern
  - Blockage is usually only a problem at short ranges
  - As the radar beam propagates, it becomes wider

Doppler Theory

- Hence, ground targets fill a smarter and smaller portion of the beam
- Blockage results in a reduction of the effective transmitted power of the radar, thus less energy is available to reach targets beyond the source of blockage

Doppler Theory

- Cone of silence
  - The cone of silence is associated with radar having upper elevation angle limitations
  - Positioning the antenna away from your station ensures power returned from meteorological phenomenon affecting you is not influenced by the cone of silence

Doppler Theory

- Side Lobes
  - Due to diffraction of the electromagnetic energy at the edges of the antenna, only about 80% of the radiated energy are contained between the half-power points of the radar beam
  - Most of the remaining 20% of the energy are broadcast in other directions in spikes or side lobes
  - These lobes extend outward only a short distance with power densities far less than is found between the half power points
  - Side lobes are presently an unavoidable and a detrimental part of any weather radar system

Doppler Theory

- While side lobe patterns for radar are similar, each type of system has its own unique pattern
- Side lobes contain low power density and thus their effective range is quite short, so the majority of their effects are seen only at close range
- Effects include:
  - » Multiple displays of a single target
  - » Ground clutter
  - » False echo tops/false intensities

Doppler Theory

- After the primary lobe, is the first side lobe that typically occurs at an angle of two beam widths off the primary lobe axis
- The energy within the first side lobe is diminished by approximately 36 dB (36 dB down) as compared to the primary lobe
- Other side lobes are generally minor compared to the first one
- In measuring the intensity of storms, side lobe detection of strong echoes adds to the energy measured by the main lobe
- The results are false echo tops in the vertical and elongated echoes in the horizontal, especially at close ranges to the antenna

Doppler Theory

- Coherency/Doppler frequency
  - **Coherent radar such as the WSR-88D have the ability to compare the phase and frequency of successive received signals in order to determine the phase shift, and hence, radial velocity**

– Pulse-Pair Processing –

- The WSR-88D's computer processors take advantage of coherency by comparing the phase of the waveform of each new pulse with that of the pulse immediately preceding it
- Anytime we measure the speed of something, whether it's a car, runner, or precipitation particle, we must compare at least two positions, in other words, we must sample it at least twice
- The more often we take a measurement or sample, the more accurate our reading will be

- Doppler radar must do the same thing, in order for it to make a measurement of speed, the radar must calculate the difference between at least two successive samples
- This is known as pulse-pair processing because the radar compares the phase-shifted frequencies of each pulse pair

Doppler Theory

- The Doppler Shift
  - **The difference in phase of the frequency between the emitted pulse and received pulse**
    - Example:
      - Typical sound wave with source moving radially at 50 knots produces a Doppler Shift of approximately 800 Hz or 8% of the original frequency, which can be easily and accurately measured
      - WSR-88D with the same target radial motion of 50 knots produces a Doppler Shift of only 487 Hz or 2 X 10^{-05} of the original frequency
      - This radar does not directly measure frequency changes

Doppler Theory

- The WSR-88D uses pulse ot pulse PHASE change instead of frequency change to determine target velocity
- This is called pulse-paired processing
- As a target changes radial position between two successive pulses, the phase of the returned signal will change from pulse to pulse
- If a target moves perpendicular to the radar viewing angle, thereby not changing radial position, the phase of the returned signal will not change from pulse to pulse
- Electromagnetic Waves and the Doppler Shift – Each wave is transmitted as an arrangement of crests and troughs

Doppler Theory

- If the returning waves have been displaced, they are said to have undergone a phase shift
  - » As long as the phase shift is less than 180° (1/2 wavelength), the amount of change can be related to a correct velocity
  - » At 180° of phase shift and beyond, the velocities become ambiguous (interpretable as 2 or more very different values)
  - » If the transmitted energy strikes a stationary target, the electromagnetic energy experiences no phase shift, and its waveform looks identical to the original wave

Doppler Theory

- If the energy strikes a target moving away from the radar, then the backscattered waves exhibit some amount of negative phase shift. If the shift is less than 180°, we can unambiguously measure it
- If the energy strikes a target moving toward the radar, then the backscattered waves exhibit some amount of positive phase shift. If the shift is less than 180°, we can unambiguously measure it
- The problem occurs when the energy strikes a moving target which causes the backscattered waves to exhibit a phase shift greater than 180°

Doppler Theory

- If the energy strikes a target moving away from the radar causing the backscattered waves to exhibit a negative of 270°, it is ambigupus. This negative 270° phase shift is seen as a positive 90° phase shift resulting in an aliased velocity,

Doppler Theory

- **Nyquist Frequency – maximum unambiguous velocity**
  - The Nyquist velocity is the velocity value which corresponds to a 180° phase shift
  - The Nyquist interval is the full range of velocities from zero up to and including the Nyquist velocity
  - The Nyquist co-interval is the entire range of detectable velocities, both negative and positive
    - Requires a wave to be samples at least twice during its length, or twice the frequency

- Samples are obtained by transmitting pulses from the radar. Therefore the frequency at which these pulses are transmitted (PRF) must be at least twice the frequency of the waveform we wish to detect
- Hence, PRF and wavelength determine the maximum velocity we can detect without ambiguity

- Since wavelength is fixed, we can compute the Nyquist velocity, Nyquist interval, and the Nyquist co-interval for any given PRF
  - » $V_{max} = \frac{(PRF)(\lambda)}{4}$
  - » Example: WSR-88D wavelength is 10 cm, use an arbitrary PRF of 1200 PPS

    V_{max} = { (1200 pps)(10cm)} / 4

    V_{max} = 3,000 cm/sec, or 30

    m/sec, or 60 kts
- Nyquist velocity = 60 kts, Nyquist interval = 0 to 60 kts, Nyquist co-interval = -60 to +60 kts

Doppler Theory

- **Radial Velocity**
  - Since only pulsed energy that returns directly to the antenna can be detected, it stands to reason that phase shifts are only observable when they occur directly along an energized beam (radial)
  - Therefore, Doppler radar can only measure the component of a target's motion, which occurs along the radial axis

Doppler Theory

- Inbound motions result in *positive* phase shifts, while outbound motions cause *negative* phase shifts
  - Motion directly Along Radial (Parallel)
    - » If a parcel moves directly toward or away from the antenna, we say its motion is parllel to the radial axis (beam)
    - » Truly parallel motions allow the phase shift of each wave to become fully visible to the radar
    - » The result: displayed velocities reflect the parcel's true speed

Doppler Theory

- Motion Across Radial Diagonally
  - » When a parcel's motion becomes diagonal to the radial axis, only some portion of its phase shift is observed
  - » Since less than maximum motion is realized, an underestimation of target speed is plotted and displayed
  - » The degree of error depends entirely on the parcel's angle and orientation

Doppler Theory

- Motion Perpendicular to Radial
  - » Since the radar antenna rotates in a full circle (360°), the parcel's orientation (to radial axis) is ever changing
  - » At some point, the parcel's motions becomes perpendicular to the radial and exhibits zero motion toward or away from the antenna
  - » Because of the radar's perpendicular viewing angle, **no** *phase shift* is observed
  - » As far as the radar is concerned, its pulse remains unaltered and no phase shift has occurred

Doppler Theory

- From this information, the parcel is considered stationary
- “Zero” velocity is displayed while the parcel’s actual speed goes undetected

Doppler Theory

- The Doppler Spectra
  - **To help you furhter understand atmospheric sampling by the WSR-88D, we will now look at the data which is being received by the radar at any one instant**
  - **Recall from our discussion of conventional radar principles that a sample volume is the volume of the atmosphere equal to ½ the pulse length time's 1 beam width**

Doppler Theory

- **The Doppler spectra is the distribution of power received by the radar at each phase within the sample volume**
- **In this section, we will add to our understanding of a sample volume, see what is contained within this volume (spectra), and then, see what the radar does with this information**

Doppler Theory

- Mean Doppler Velocity
  - Recall that a sample volume is the volume of the atmosphere instantaneously sampled by radar
  - Since the sample volume is relatively large, individual targets are much smaller than the sample volume
  - This means that all targets within that volume contribute to the backscattered radiation received by the radar
  - The individual targets within a sample volume may be moving in many different directions and speeds
  - The pulsed Doppler weather radar doesn’t sense these motions individually

Doppler Theory

- At any one instant, it receives a combination of the motions of the individual particles within the sample volume
- Since this return consists of many different motions, it also consists of many different electromagnetic frequencies
- The radar then processes these various frequencies and interprets them in terms of a Doppler Spectrum
- The radar electronically analyzes the spectra to determine the phase returning the maximum power
- Notice that the distribution of power plotted against phase results in a bell curve

Doppler Theory

- This curve shows the amount of power returned to the radar at any one phase (Remember that we can translate these frequencies into velocities)
- The top of this curve is the maximum power returned to the radar and is what is used for the Base Velocity product
- You might then assume the phse representing the greatest power return would also represent the motion of the greatest number of particles within the sample volume
- However, this is not necessarily true
- Since the radar receives proportionally much more reflected power from large drops than from small ones, the phases with the maximum power returned is usually that of the largest particles within a sample volume

Doppler Theory

- Spectrum Width
  - Motion of smaller particles within the sample volume can be determined from portions of the spectrum to the right or left of the curve center
  - In other words, information on the most variable short-term gustiness or turbulence within the sample volume are in the extremes of the spectrum

Doppler Theory

- Spectral Shape
  - The variance is used as a mathematical description of spectral shape
    - » *The WSR-88D uses the variance so it can describe the range of shifted frequencies received by the radar*
    - » *The radar derives this variance by normal statistical rules, then translates this statistical data into spectral shape information that a product you can view graphically*
    - » *Spectral shape information can be described in terms of a distribution's standard deviation*

Doppler Theory

- *If the frequency (f) corresponds to the mean Doppler velocity, then half of the total area under the curve falls both right and left of “f”*
- *The standard deviation is that distance to the right and left of the “f” which includes about 2/3 of the area under the curve*
- *The square of the standard deviation is called the variance, and it changes as spectrum width varies*
- *Wider spectra generally indicate more turbulent targets*

Doppler Theory

- *Since we said that the variance changes with the spectrum width, larger values of the variance also correspond to more turbulent targets*
- *We use this variance as an indication of spectral shape*
- *The variance is displayed by the WSR-88D as a graphic product in a similar way it displays reflectivity or velocity*
- *During interrogation, you can simultaneously examine patterns of mean Doppler velocity, reflectivity, and variance (spectrum width)*
- *From this you can determine whether you should have confidence in your mean air flow and turbulence evaluations for various portions of a precicipitation target*

Doppler Theory

- Target Spectral Characteristics
  - » *The actual shape of the Doppler spectrum varies with the character of the target being sampled*
  - » *Precipitation echoes with very large particles and large internal wind shears (thunderstorms) result in a flatter appearing spectrum*
  - » *However, the spectrum for these targets have substantially more area under the curve than other targets since the particles are larger and reflect more power back to the radar*
  - » *Targets with similar particles and weaker wind shears produce a sharper spectral shape with much less area under the curve*

Doppler Theory

- Radar Spectral Characteristics
  - » *The Doppler spectral shape is determined by the nature of both the target and the radar*
  - » *In the generalized discussion of spectral shape that follows, keep in mind that characteristics of precipitation targets vary widely, and thus, their Doppler spectra vary widely*
  - » *We noted earlier that the narrower and sharper spectra produces more reliable mean velocity estimates of the sample volume*
  - » *However, some of the variance seen in a spectra may be caused by the radar itself and shouldn't be interpreted as turbulence*

Doppler Theory

- *For example, stabilizing the Doppler velocity estimate (a narrow spectrum width) can also be achieved by increasing the antenna size*
- *This reduces the beam width, which, in turn, reduces the sample volume and amount of variability*
- *Also, slowing the antenna's rotation stabilizes the velocity estimates by allowing repeated sampling of a given atmospheric volume*
- *This produces a better estimate of velocity since a slower rotation allows for more sequential samples, and therefore, a more reliable estimate of mean velocity*
- *The WSR-88D uses this slower rotation for sampling the clear air*

Doppler Theory

- You must also realize that a high spectrum width does not always equate to turbulence and or wind shear
- Always keep in mind that a high spectrum width may be due to weak reflectivity causing a poor signal-to-noise ratio
- Also, we tend to see higher spectrum widths along the edges of echoes where power return drops off rapidly

The Doppler Dilemma

- The maximum precise–range measurement is limited by the pulse repetition frequency (PRF) while the maximum, precise-velocity measurement is limited by the wavelength of the radar and pulse repetition frequency

The Doppler Dilemma

- PRF's Effect on Range/Velocity
  - **Range**
    - Increasing PRF decreases listening time, which effectively decreases unambiguous range
    - Decreasing PRF increases listening time effectively increasing unambiguous range

The Doppler Dilemma

- **Velocity**
  - Increasing PRF increases the Nyquist or maximum unambiguous velocity
  - Decreasing PRF decreases the Nyquist velocity or maximum unambiguous velocity

The Doppler Dilemma

- **The Dilemma**
  - Decreasing the PRF to extend radar range decreases the extent of observable velocities
  - Thus, increasing the PRF to extend the range of observable velocities (V_{max}) decreases the maximum unambiguous range (R_{max})
  - This inverse relationship between V_{max} and R_{max} is the Doppler Dilemma caused by limitations placed on our pulsed-Doppler radar
  - The WSR-88D employs methods to mitigate the Doppler dilemma

The Doppler Dilemma

- We'll examine those methods, but first let's take a closer look at velocity and range ambiguities
  - Aliased Velocities
    - » *Velocity is a measure of phase change between the transmitted phase and received phase*
    - » *In Doppler radar, a transmitted pulse has the same waveform as phase-shifted pulse*
    - » *The radar uses this information to make very precise measurements of speed*

The Doppler Dilemma

- *Remember, the maximum velocity or Nyquist co-interval detected by the radar is equal to the pulse repetition frequency (PRF) multiplied by the wavelength divided by four any wind speed that exceeds this value is aliased by the radar*
- *For example. If the V_{max} is ± 50 kts and the environmental wind is 60 kts, Doppler velocity values in excess of 50 kts are aliased*
- *The aliasing process offsets true Doppler velocity values by multiples of 2 (V_{max}) until they fall within the Nyquist co-interval*

The Doppler Dilemma

- Range folding
  - » *A pulse-Doppler radar, like a conventional radar, transmits a series of pulses that are separated in space by a distance (d)*
  - » *The maximum range a pulse cann travel and return before the next pulse is transmitted is one-half the separation distance*
  - » *The maimum unambiguous range is equal to the speed of the pulse (speed of light) divided by two times the PRF*
  - » *The range of a scattering region from the radar is computed from the time a pulse is transmitted until signal is received back at the radar*

The Doppler Dilemma

- *However, if the return from a target is at a range greater than the maximum unambiguous range, then the radar will not receive the return, until after the next pulse is transmitted*
- *Such returns are referred to as second trip returns*
- *For a constant PRF, the radar processing equipment is not able to distinguish between first trip and second trip returns*
- *Thus, all measured ranges are potentially ambiguous because, without additional information, it is not possible to determine the proper trip to which a returned signal should be assigned*

The Doppler Dilemma

- *The range folding problem can be solved by decreasing the PRF until the maximum unambiguous range meets or exceeds the radar's displayable range*
- *However, this solution introduces an additional problem for the WSR-88D*
- *By decreasing our PRF to mitigate range ambiguities, we have increased the potential for velocity aliasing*
- *So how can the radar determine how to alleviate both range and velocity ambiguities?*
- *Next, we'll look at how this is done through the employment of strategic planning, algorithms and adjustable PRF's*

The Doppler Dilemma

- The WSR-88D employs three methods to mitigate the effects of the Doppler dilemma
  - **Strategic scanning uses combinations of low PRF's (surveillance) and high PRF's (Doppler) to unfold range overlaid echoes and dealias velocities**
    - Data collected at high PRF's are used to collect velocity data unambiguously
    - Data at low PRF's are used to collect reflectivity data to range unfold the velocity data
    - In the low elevations, the radar scans each elevation slice twice, once at a low PRF and again at a high PRF

The Doppler Dilemma

- At mid-elevations an interlacing of low and high PRF's referred to as batch mode, is used
- In batch mode, four Doppler (high PRF) pulses and a single surveillance (low PRF) pulse are continuously cycled at each mid-level elevation slice
- In the upper levels, only Doppler PRF's are used since the beam is above all scattering regions except the region found within the radar's maximum unambiguous range or the first trip

The Doppler Dilemma

- **Range Unfolding Algorithm**
  - The range unfolding algortihm does a comparison between the surveillance and Doppler returns
  - In areas of overlapping returns, a range bin to range bin power comparison is done between the first and all subsequent trips
  - If the difference meets or exceeds the Range Unfolding Overlay Threshold (TOVER), the algorithm will assign the higher velocity value to that range bin
  - The other will be range folded
  - If the comparison does not meet the TOVER, both bins will be range folded

The Doppler Dilemma

- **Velocity Dealiasing Algorithm**
  - To compensate for the radar's inability to detect phase shifts of greater than one-half wavelength, the radar's computers employ a velocity dealiasing technique
  - Velocity dealiasing is accomplished by testing for velocity continuity along a given radial
  - It uses the assumption that true wind velocities are more or less continuous
  - In other words, adjacent veloctities should not change drastically over a small linear distance

The Doppler Dilemma

- Without the use of dealiasing, these aliased values would be incorporated into the velocity product leading to a confusing display
- The radar’s computers use a velocity dealiasing technique, which compares the current aliased velocity with the preceeding values and adjusts accordingly
- This is a very simplified explanation of the dealiasing technique used by the WSR-88D
- However, it is important you realize that when velocity differences greater than a specified value occur from sample to sample, velocity aliasing is assumed to have occurred and the WSR-88D attempts to solve this problem through dealiasing

The Doppler Dilemma

- **Adjustable PRF's**
  - When a significant protion of a storm of interest is overlaid by range folding, it is possible to shift the echoes relative to each other by changing the PRF
  - The capability for changing the PRF increases the probability that velocity data for a storm of interest can be protrayed without interference from multiple-trip echoes
  - The ability to change PRF's is limited to five defined Doppler PRF's residing within the WSR-88D

- APPLICATION: Students will practice on appraisal packages in class
- EVALUATION: Administer A-501a now and the Written Test at the end of the unit